

AN URBAN CLASSIFICATION APPROACH BASED ON AN OBJECT-ORIENTED ANALYSIS OF HIGH RESOLUTION SATELLITE IMAGERY FOR A SPATIAL STRUCTURING WITHIN URBAN AREAS

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ABSTRACT

Classifying the complex structures of urban morphology from high resolution remote sensing imagery comprises difficulties due to their spectral and spatial heterogeneity. This paper presents a methodology allowing to derive meaningful area-wide spatial information for city planning and management from IKONOS imagery. The initial point is a stable segmentation for an object-oriented approach to derive a thematic land cover classification. The classification methodology – which is predominantly based on shape and neighbourhood related features - will be exemplified by the extraction of roads with a region-growing rule base. The approach follows the assumption that objects representing real world structures correspond in any urban area. Finally, the urban land cover classification is used to compute a spatial distribution of built-up densities within the city and to map homogeneous zones or structures of urban morphology. The aim apart from the information on urban morphology is the opportunity to derive indirectly standard socio-economic data for further support of city management and planning. The result shows an allocation of different urban zones within the city of Istanbul with an accuracy of 82% compared to a digitized layer based on visual classification.

1. INTRODUCTION

Up-to-date and area-wide information management in highly dynamic urban settings is a critical endeavour for their future development. Especially in explosively growing and altering megacities a lack of up-to-date data is apparent. For this purpose remote sensing offers the possibility of a fast and area-wide assessment of urban changes and developments. This paper describes a work-flow from an original high resolution satellite image up to a differentiation of inner urban morphology.

The challenge of classifying urban land cover from high resolution remote sensing data arises from the spectral and spatial heterogeneity of such imagery. The frequent alternation and coexistence of built-up structures, vegetation, bare soil or water areas and the heterogeneity of the objects themselves (for example roads with cars) result in distinct spectral variation within these areas of literal homogenous land cover classes. Thereto the high dissimilarity of functions like industrial or residential areas as well as parks or agricultural regions causes problems in terms of an indirect inferring of land use. In order to characterize this complex highly-structured urban environment, an object-oriented approach with shape parameters and neighbourhood relations provides additional analysis potential from remote sensing apart from spectral information.

A multiresolution segmentation approach was presented by (1). Segmentation concepts and their theoretical background for object-oriented approaches (2) have already been summarized. In this context a recent segmentation procedure (3) has been applied to derive

real world structures. Object-oriented classification methods have been presented by (4) or (5). Classification approaches of highly-structured urban areas (6), (7) are objects of research. An automated extraction of straight roads in an urban environment (8) from high resolution satellite imagery is an example of such classifications. It has been illustrated how remote sensing can contribute to an inner urban differentiation (9).

This paper presents an object-oriented approach allowing to derive a simple transferable urban land cover classification. Based on an initial segmentation the urban land cover classes are derived and homogenous urban density zones are differentiated. The assumption that homogenous urban patterns or morphologies correlate with urban function as well as with social-economic parameters (10) has been verified. In conclusion, the urban zoning is an important approach for fast monitoring and extraction of further standard parameters for management or planning of large complex urban areas.

2. TEST SITE AND DATA

Istanbul as a highly dynamic and rapidly developing megacity has been chosen as test site. The megacity located on the fringe area between Asia and Europe with its estimated 14 million people lives through enormous demographic, cultural and economic changes. This transition is reflected in physical urban parameter like the morphology or spatial patterns as well as in urban sprawl. To analyse the complexity of inner urban structures a high spatial resolution satellite image of IKONOS was used. It features a geometric and radiometric quality of 1-m panchromatic, 4-m multispectral and 1-m pan-sharpened imagery.

3. METHODOLOGY

After the pre-processing of the original image in terms of an atmospheric correction, the starting point is the segmentation process for an object-oriented analysis and a classification approach based on predominantly shape features. With a region-growing classifier the extraction of road elements are shown. In this context the main focus is set on easy transferability. The classification approach is the basis for further analysis of city morphology. Finally, the example of an urban zoning based on density measures is calculated.

3.1. SEGMENTATION

One of the most important issues in the context of an object-oriented classification is the accurate segmentation of the input images. The basic task of segmentation algorithms is the merge of image elements based on homogeneity parameters or on the differentiation to neighbouring regions (heterogeneity), respectively (2). Single pixels do not represent the important semantic information necessary to interpret an image like meaningful image objects and their mutual relationships do (1). The resulting segments come closer to the spatial and therefore spectral and textural characteristics of the real world structures. Additionally, various shape-related or context-related attributes are provided. As an "ideal" object scale does not exist, objects from different levels of segmentation (spatial) and of different meanings (thematic) have to be combined for many applications. Figure 1 shows the hierarchical network of segmentation levels and its advantage to enforce the possibility of creating an arbitrary number of segmentation levels with segment sizes optimized in terms of the best fitting representation of the real world structures.

Figure 1 shows the number and the sizes of segments in different segmentation levels. The high variability of shapes in urban areas from small structures like houses up to large shapes of inner urban open spaces requires a high number of exactly adjusted segmentation levels. Displaying segments matching real world structures in one level would be advantageous for an optimal utilization in the classification process. An approach to optimize segments in one

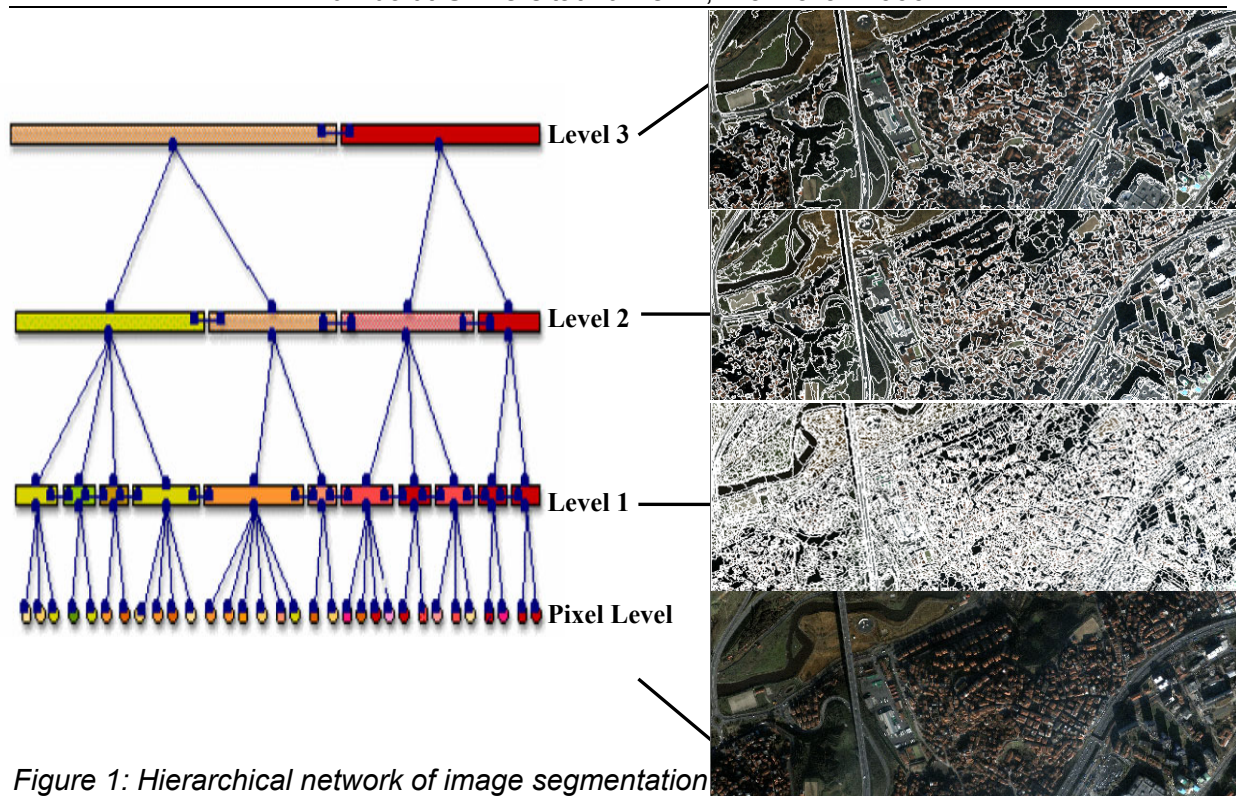


Figure 1: Hierarchical network of image segmentation

level has been presented by (3), that is the possibility of reproducing large segments representing for example vegetation areas by a large segment and houses by small segments side by side without additional segment merging after a thematic classification process. The classification-based optimisation procedure also ensures a more comparable and therewith constant segmentation. The basic idea behind this approach is to iteratively optimise the shape of the image objects according to a rule base that affords the identification of significant individual structures.

The segmentation optimisation starts with the generation of an initial “base level”. This segmentation is characterised by a very low scale parameter in order to ensure an accurate representation of all small structures of the real world. Subsequently, a second “optimisation

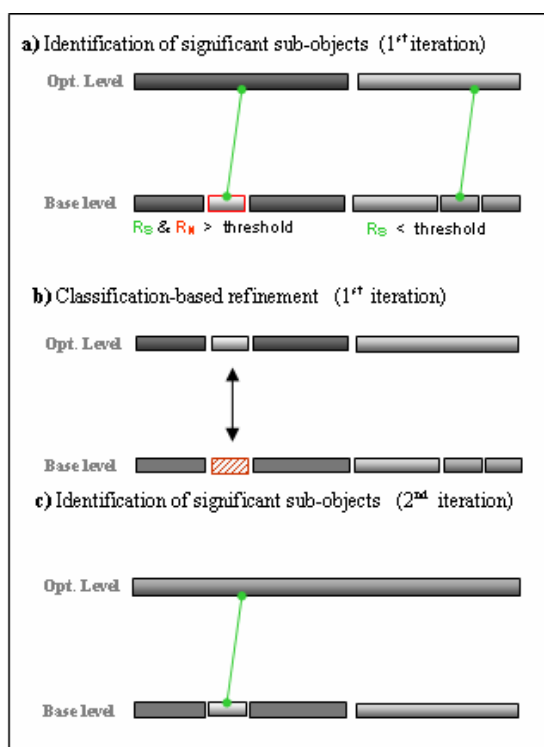


Figure 2: Image segmentation optimisation

level” with an increased scale parameter is generated above. Then it is decided for each segment of the base level, whether it represents a part of its super-ordinate object of the 2nd level or whether it can be seen as an individual structure. In short, the segments of the base level are classified as a significant sub-structure if their spectral behaviour to the respective super-ordinate segment exceeds a predefined threshold (3). Next, these segments of the optimisation level covering a base-level-object which is classified as a “significant sub-structure” are modified. This is done by clipping the respective segment of the optimisation level according to the shape of the identified sub-structure. Finally, the base level is deleted and then a new optimisation level with significantly increased scale parameter is generated. Thus, the former optimisation level becomes the base level and

the new, coarser optimisation level will be optimised again.

This procedure is iteratively performed with a continuously increasing scale-parameter for the generation of the optimisation level. The final output of this approach provides a single, improved segmentation level that features large segments in homogeneous areas whereas small-scale structures and heterogeneous regions are represented by distinctively smaller image objects. To enable both the calculation of meaningful texture measures and the utilisation of hierarchical features, the optimised level is supplemented by a very coarse level on top. Finally, a third segmentation level with small objects is segmented underneath.

Figure 3 shows a highly structured urban morphology taken from an IKONOS imagery. The optimized segmentation mapped in Figure 3 presents objects reflecting an approximation of real world structures. Roads and the river are mainly represented by long and narrow segments, but a complete generalisation is difficult, due to for example different shapes on roads through cars. Heterogeneous housing areas are noticeably represented through a high number of small segments highlighting the complex urban built-up structure. Vegetation areas as well as a few shadow areas are displayed by larger segments of low compactness.

Compared to figure 1 real world structures are now represented by segments corresponding in shape and size in one segmentation level, while in figure 1 each object type had to be adjusted in an individual level.

a) Original IKONOS imagery



b) Segmentation

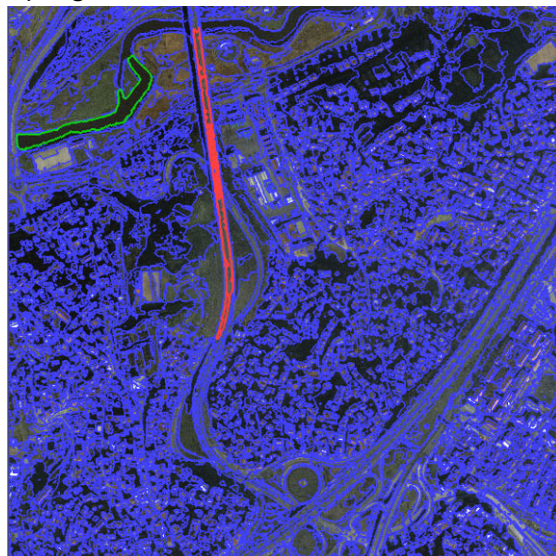


Figure 3: Optimized segmentation of an IKONOS imagery in a highly structured urban area and its typical segment shapes

3.2. REGION-GROWING CONTEXT-BASED CLASSIFICATION ALGORITHM IN PARTICULAR BASED ON SHAPE FEATURES FOR EASY TRANSFERABILITY

Due to spectral heterogeneity caused by different atmospheric conditions or different recording times, an automated transferability of a classification rule base is hardly realisable. This region-growing context-based classification rule-base was developed under the premise of mostly avoiding spectral classification features. Transferability then depends then on an adjustment of a few values, as long as the segmentation process delivers typical segments of characteristic objects.



After image segmentation the next goal is to set up a robust rule base which allows for an accurate classification. In this context the identification of robust features for the class description is a key issue. Considering the spectral complexity of urban land cover, there are

specific limitations in the separation of built-up and non-built-up materials and of roofs and roads and of different roof types (4).

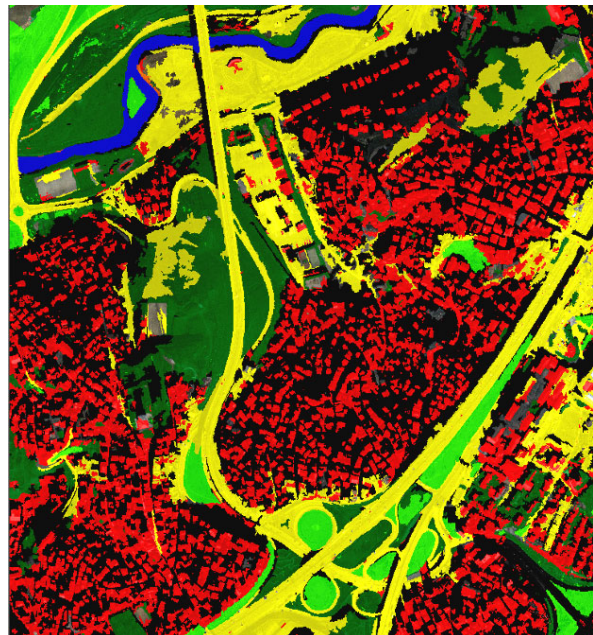
Based on the generated objects - ideally representing all the real world structures in urban areas - a region-growing algorithm has been implemented for a very high fuzzy classification probability. This classification approach was predominantly based on shape features. The key-note for the adjustment of this classification algorithm contains the assumption that spatial segments like houses or roads correspond in any urban area. While for example roads normally result in a high ratio of length to width of the segment, houses result in lower values of this ratio. Based on the segmentation the first step comprises a detection of a few segments with a very high membership probability based on shape features and supported by the spectral ratio NDVI (Normalized Difference Vegetation Index). Although transferability becomes limited as soon as spectral features are part of the classification methodology, because reflection values vary due to, for example different recording time or different atmospheric circumstances, they are needed for a superior classification certainty. The only spectral feature used in the classification process is the NDVI. All remaining features are shape-related and neighbourhood-related attributes. Thus, easy transferability for urban land cover classification can be achieved with a few adjustments due to different spectral values.

a) Region-growing road extraction



| | |
|---|---|
|  Road step 1 |  Road step 3 |
|  Road step 2 |  Water |

b) Urban land cover classification







| | |
|---|--|
|  Trees/brushes |  Houses |
|  Lawn |  Shadow |

Figure 4: Region growing algorithm based on shape features for road extraction and final urban land cover classification

As an example the extraction of roads in Istanbul is presented. A priori to any further analysis a vegetation mask based on the NDVI and shape features is set up. Subsequently, the first step is the detection of a few typical road segments. The shape features length and length to width are the deciding features. In addition the spectral feature NDVI is used, so that classification mistakes of random similar shape segments of 'not roads' are eliminated. It has been emphasized in figure 4 through the highlighting of two similar shapes representing a river and a road that solely utilising shape information is not sufficient for an accurate identification. With those three features in step 1 (figure 4a) a very high fuzzy classification probability for road membership can be achieved. At step two, the same features with softened membership values are used to classify, but as an additional feature a boundary to roads (direct neighbourhood) detected in step 1 is necessary. This procedure is repeated

and the result is for each step an increase of thematic allocation, a region-growing, along the roads. Analogical to the road extraction, more thematic classes are detected. Figure 4b shows the final urban land cover classification result.

3.3. PROBLEMS AND ACCURACY ASSESSMENT

The region-growing algorithm for road extraction causes problems when the shape feature does not correspond to the expected shape. Facing the high spectral heterogeneity of cars or complex street formations with a lot of shadows or curves the classification algorithm reaches its limitations. The different shapes of the segments caused by cars disconnect the growing function and leave unclassified road stages. In the example of figure 5, the algorithm detects almost completely all major roads, but also comes to its limits within the high structured urban housing zones, where roads can only be assumed due to the coverage of shadows in the narrow sea of houses.

Using shape and neighbourhoods more thematic urban land cover classes like houses, shadows and water are classified, while the two vegetation classes have already been detected a priori to the road extraction. The object-oriented land-cover classification result of highly-structured urban morphology has been analysed for an accuracy assessment. The object-oriented basic classification of built-up areas has been compared to cadastral GIS data. The accuracy shows an average of more than 82% of houses [m²] have been recognized.

3.4. FURTHER ANALYSIS OF URBAN PATTERNS AND MORPHOLOGY

A spatial differentiation in specified homogenous spatial units or zones within a city can deliver insight into urban structuring, urban morphology and urban development. As an example, the result of the derived land cover classification of an urban area has been used for a computation of density zones to deliver additional information for city planning. Based on the prior land cover classification a moving window approach has been implemented. The window calculates the rates of pixels being classified as built-up, vegetation, water, shadow and infrastructure in the distance of 20 and 200 meters to each side of the middle pixel. The near neighbourhood and the 400 pixel surrounding density value calculation have their theoretical background in a more flexible approach to classify homogenous density zones in consideration of near neighbourhoods to detect transition zones and to embed the zone in respect to the whole structure of the quarter. Table 1 shows the membership parameter for four different urban zones based on built-up density and vegetation rate, which are mapped in figure 5.

Table 1: Detection of four different zones by density parameters

| | High dense built-up area | Dense area | built-up | Loose area | built-up | Open spaces |
|--------------------|-----------------------------|---------------|----------|---------------|----------|-------------|
| Built-up density | > 50 % | > 40 % | | >15 % & <40 % | | < 10 % |
| Vegetation density | < 5 % | < 15 % | | > 20 % | | > 85 % |

Remote sensing can support city planning especially in hardly manageable megacities, where moving-in rates are exploding and the dynamics of urban development results in the rapid changing of urban patterns. Thus, up-to-date information management is particularly difficult in megacities. In view of this difficulty remote sensing can provide an up-to-date and area wide assessment of dynamic urban situations. Important factors of the specific urban environment are the population and built-up density on the one hand, and the amount and distribution of open spaces on the other hand (9). Figure 5 shows an allocation of four different density zones, high dense, dense, loose dense and open spaces calculated from the land cover classification result. The three built-up density zones act as homogeneous zones to infer standard socio-economic parameters like population density. In our example

the inner differentiation of the city of Istanbul identifies a decrease of built-up density from west to east which matches increasing distance to the city centre. Not only a decrease in built-up density areas can be recognized, but also an increase of open spaces.

This inner differentiation of city morphology provides wide application possibilities to support city management. For example a comparison between built-up density and its dependent parameter population distribution and open spaces allows an analysis of possible camp spaces in case of the need of emergency accommodation after a natural disaster like earthquakes. Further, the quantification of sealed surface within urban areas for hydrological support or monitoring of urban sprawl as well as inner urban changes are also application examples.

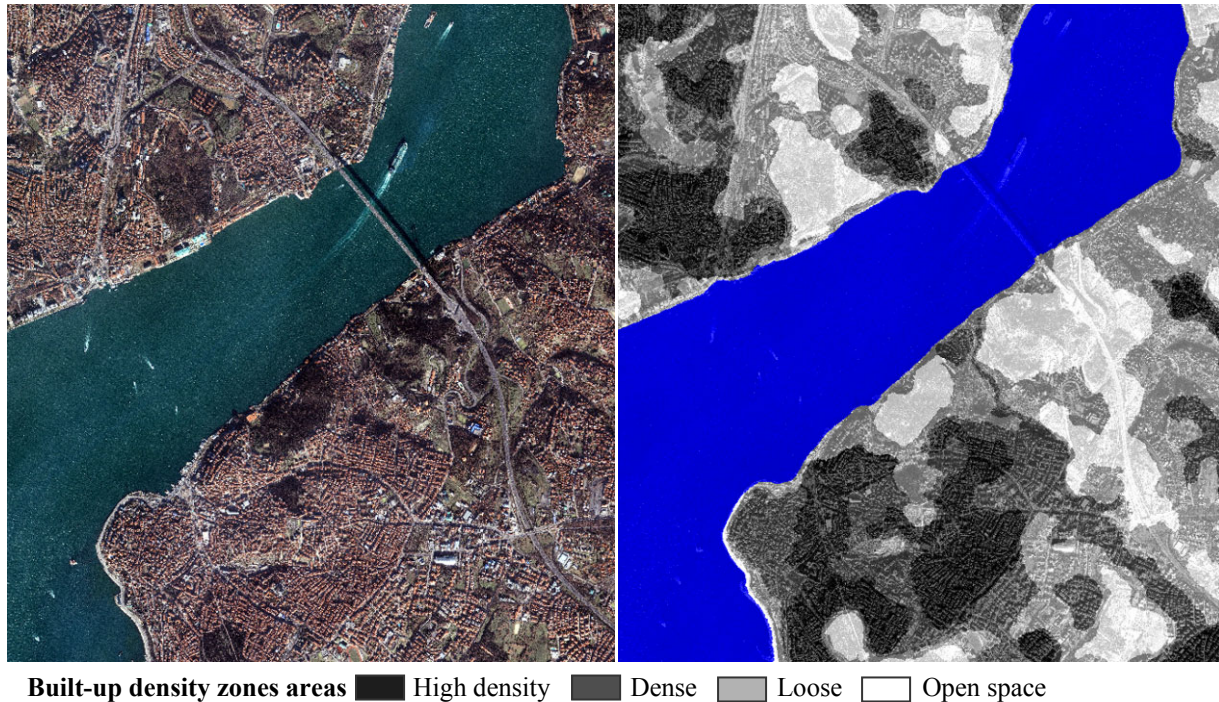


Figure 5: Built-up density zones compared to the original IKONOS imagery

An accuracy assessment of the homogeneous density zones is difficult because of the lack of a standard norm. Therefore the accuracy has been assessed by a comparison of the calculated zones to a digitized layer with visual allocation of homogeneous density zones. The overall accuracy result was 82% compliance.

4. SUMMARY AND CONCLUSION

A methodology has been presented to gain an urban land cover classification from IKONOS imagery by means of a stable segmentation and a region-growing rule-base. The specification on shape and neighbourhood features for the thematic membership allocation ensures a fast transferability with adjustment of the only used spectral parameter NDVI. The land cover classification result has been computed to derive additional information for urban planning. The density rates of the thematic land cover classes have been calculated and serve as classification values for an allocation of homogenous urban morphology zones within the city. This structuring of urban patterns and morphology can deliver insight not only into current spatial arrangements, but also in monitoring a temporal change and hence convey spatial dynamics of complex urban development. Once one understands the mechanism of urban dynamics, one can formalize it and model urban growth. It is essential for future city planning to know what results different real-world decisions produce.

Further research will concentrate on the correlation of socio-economic parameters to these homogeneous zones. The connection between physical urban morphology and socio-economic variables can centre remote sensing for the support of city planning with a fast, area-wide spatial analysis of highly-structured urban areas.

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